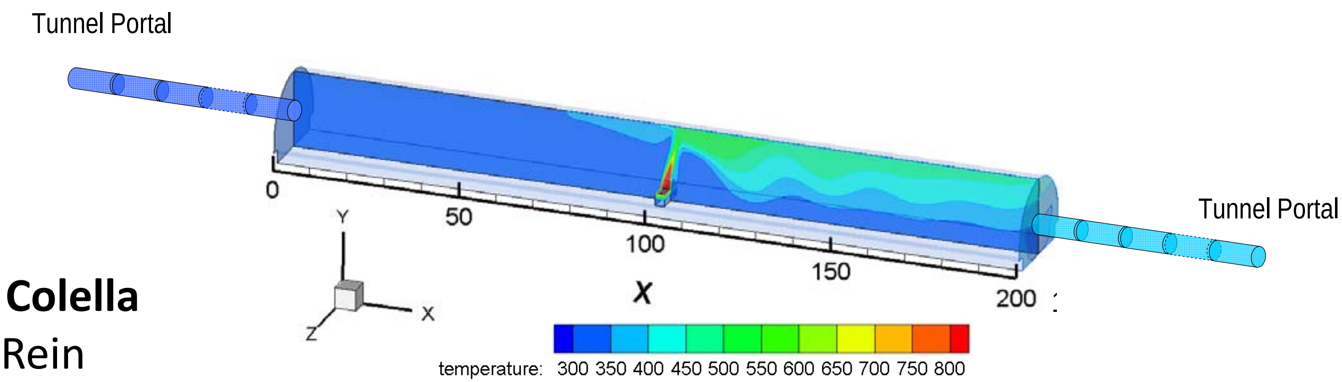
GDR CNRS n°2864
17-18 June 2010

Multiscale analysis of tunnel ventilation flows and fires



Dr. Francesco Colella
Dr. Guillermo Rein
Prof. Vittorio Verda
Prof. Romano Borchiellini
Prof. Jose L. Torero

Dipartimento di Energetica – Politecnico di Torino

Introduction - Ventilation system

The most widespread safety system in tunnels is the ventilation system

- **Normal operating conditions**
  - visibility
  - pollutant concentrations
- **Emergency conditions**
  - Smoke management
  - safe evacuations
  - fire fighting

Introduction - Ventilation system

The flow conditions within tunnels are dependent on the combined influence of:

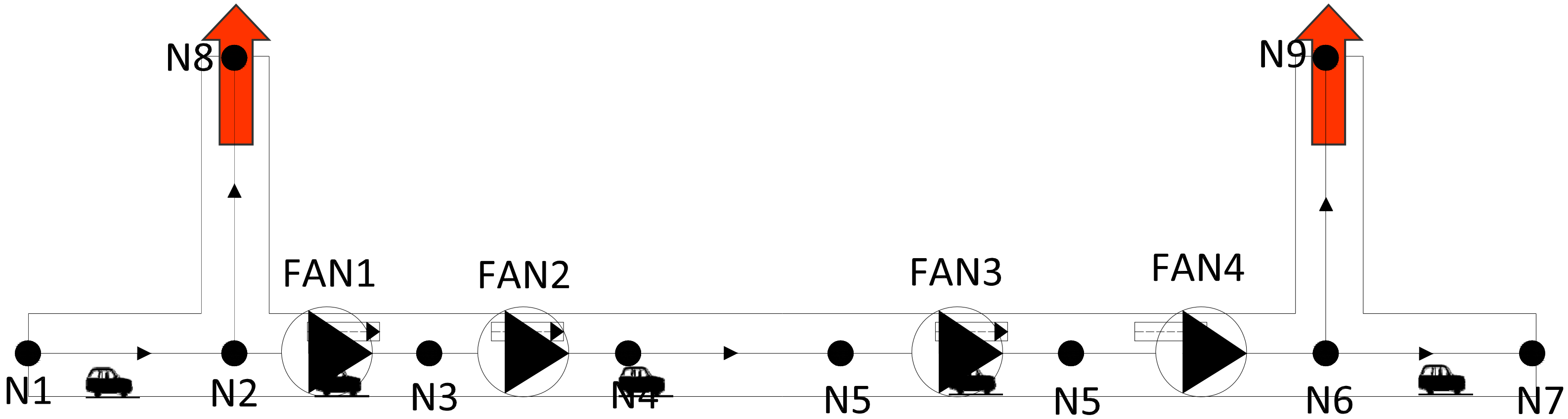
- Ventilation devices (axial and jet fans)
- Tunnel layout (slopes)
- Boundary conditions at the portals
- Blockages within the domain
- Fire size and Location
- Comprehensive analysis has to consider the whole system and not simply a part of it

1D Network model - characteristics

- Fast simulations
- Straightforward definition of boundary conditions
- Predict the global behaviour of coupled systems
- Well established for <u>design purposes</u>

BUT

- Need calibration constants
- Provides only ballpark figures

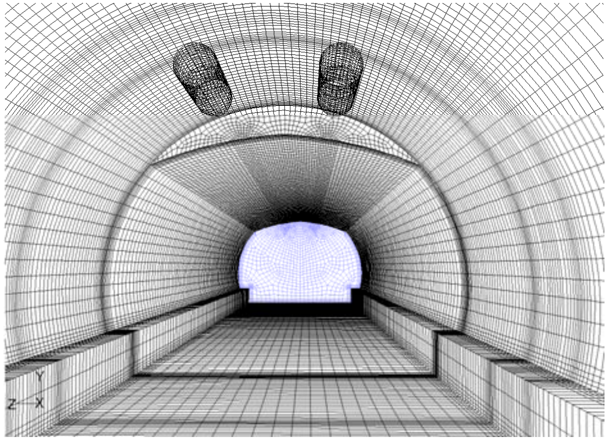


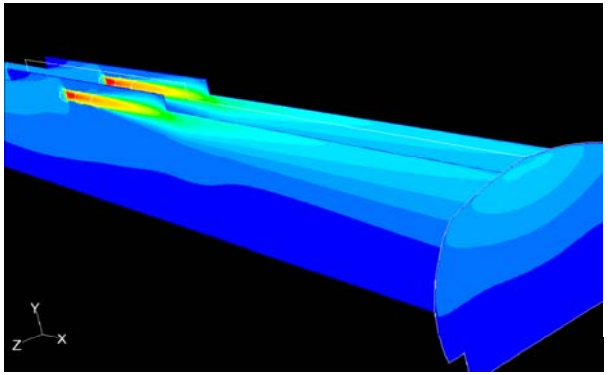
CFD model - characteristics

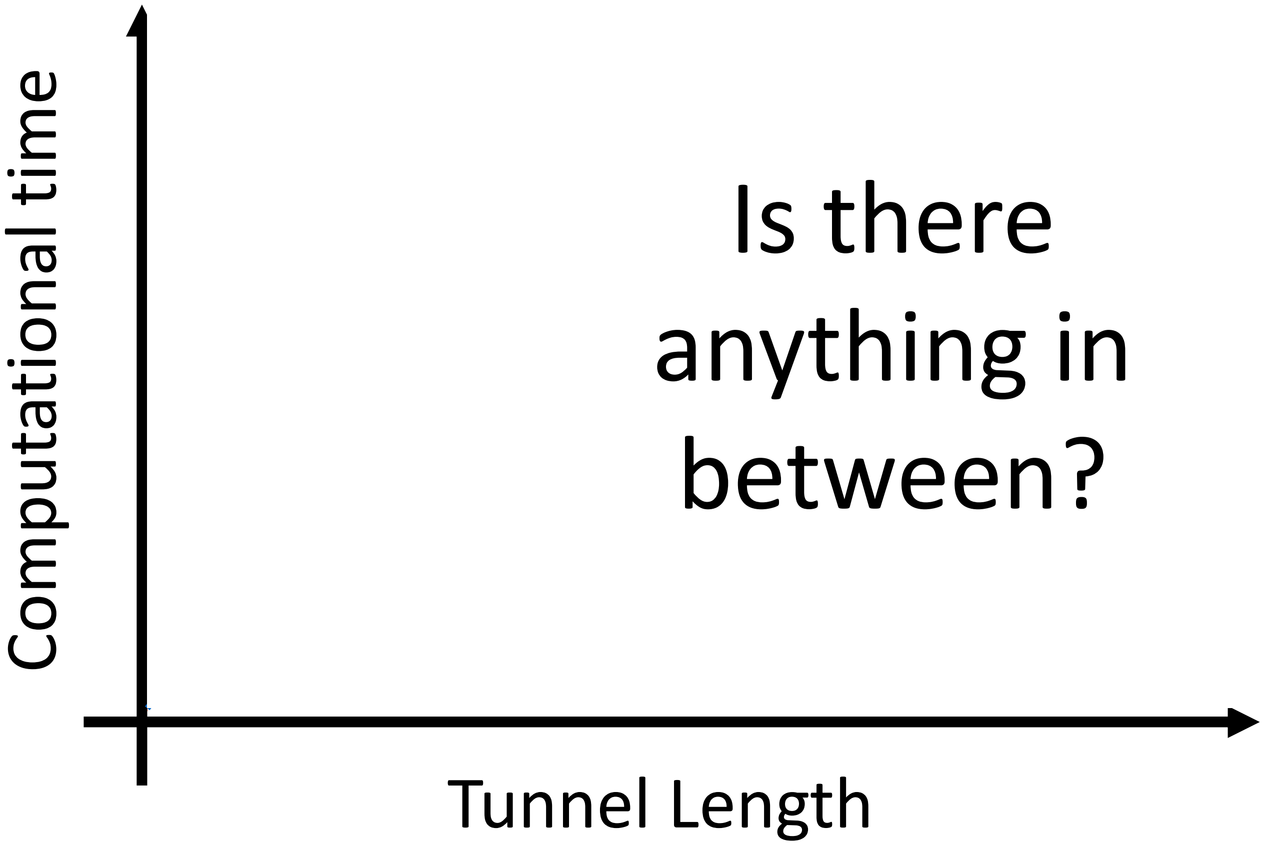
- Detailed flow field representation
- Well established for <u>design verification</u>

BUT

- Large computational time
- Not affordable for long tunnels or for analysis of ventilation strategies
- Still limited results due to uncertainties in modelling turbulence, combustion, radiation and pyrolysis of condensed fuels
- "Acceptable" accuracy for global quantities (i.e. back-layering distance)
- "Poor" predictions of local flow field data



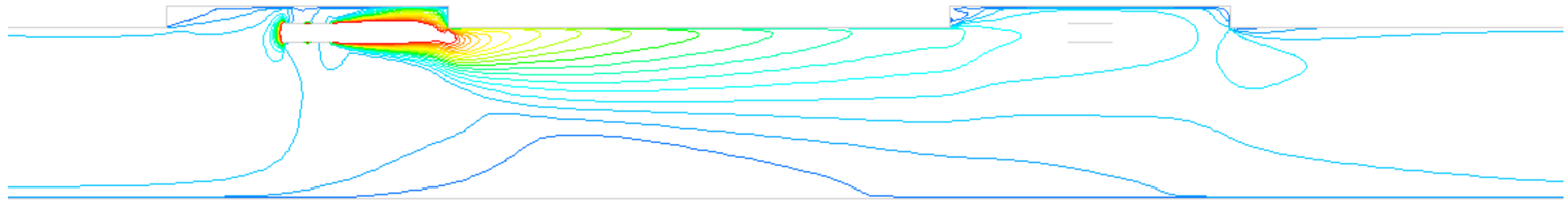




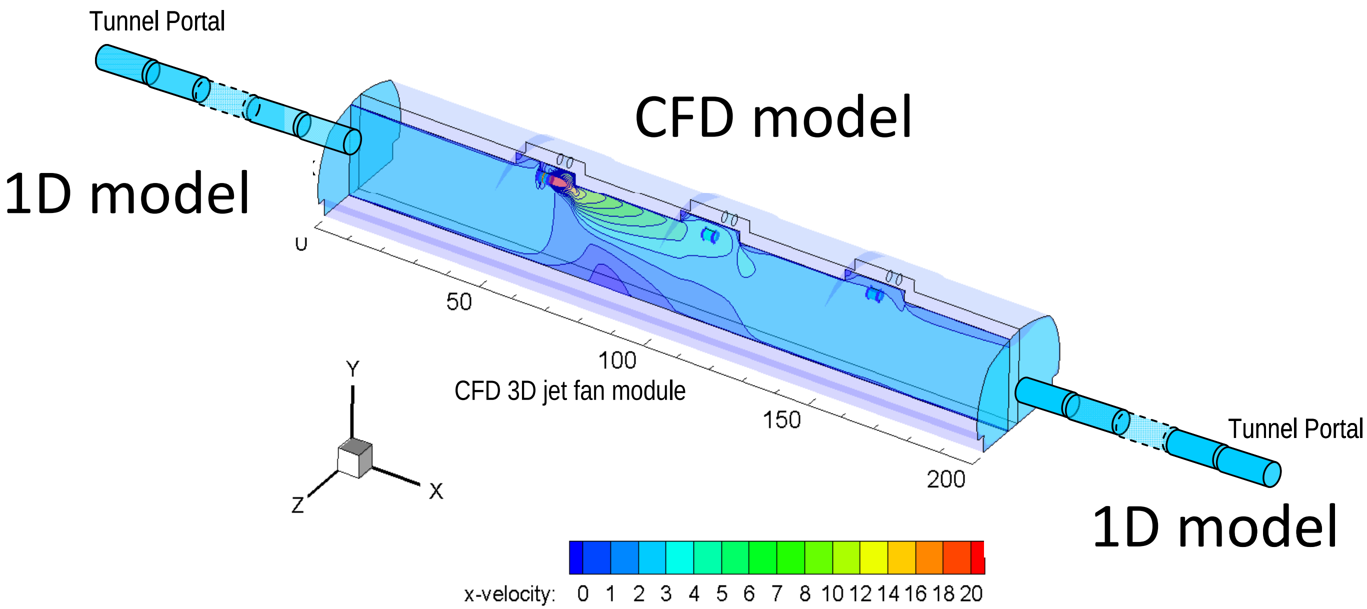
Is there anything in between?

Multiscale model - introduction

Typical velocity contours in presence of jet fans

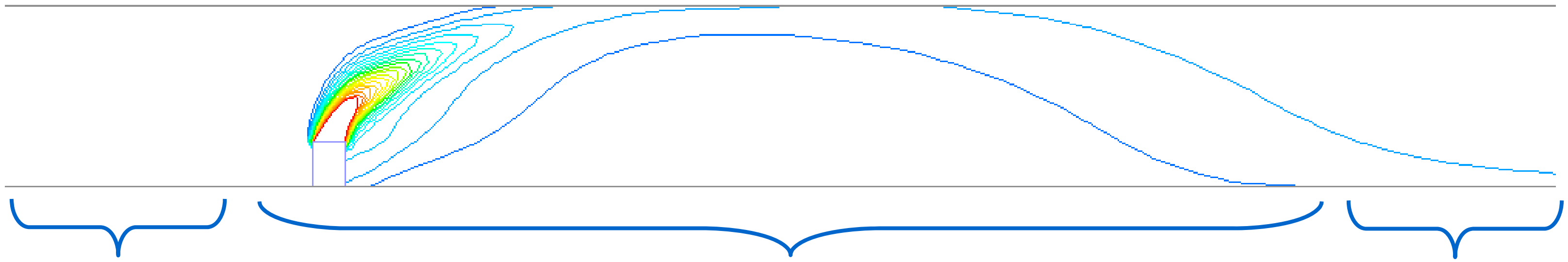


1D region 3D region 1D region



Multiscale model - introduction

Typical temperature contours in presence of fire



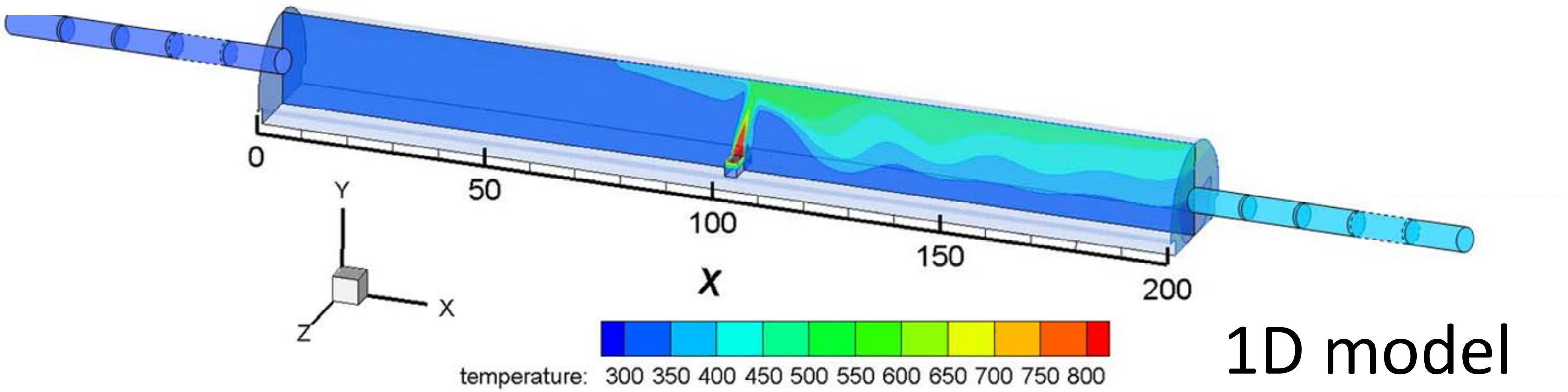
1D region

3D region

1D region

1D model

CFD model



1D model

Multiscale – coupling procedure

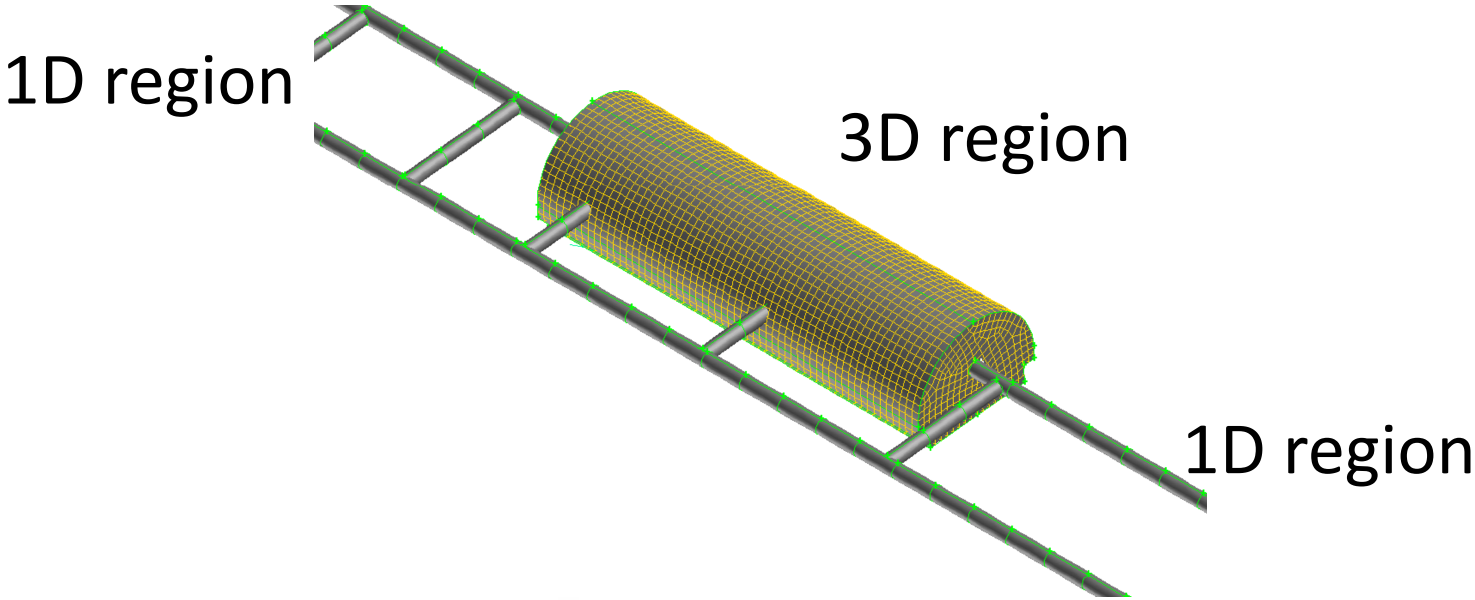
Physical decomposition of the domain

1D Regions

- Low velocity/temperature gradients
- Mono-dimensional models can be used

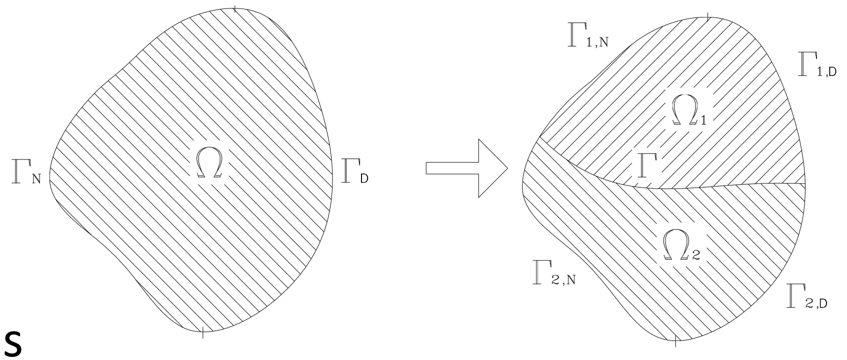
3D Regions

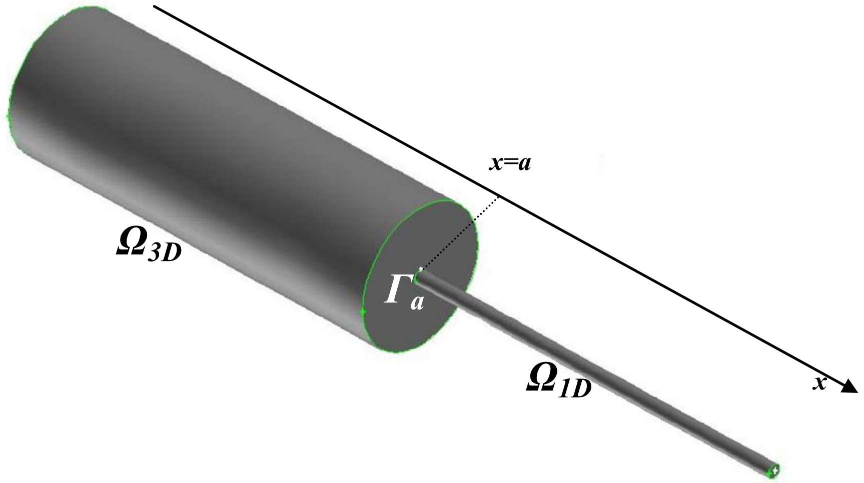
- High velocity/temperature gradients
- CFD models must be adopted



Multiscale – coupling procedure

- Based on Dirichlet-Neumann methods
- Use non-overlapping domain decomposition
- Neumann-type boundary condition applied to the CFD sub-domain interfaces
- Dirichlet-type boundary condition applied to the 1D sub-domain interfaces.
- The model guarantees the continuity of average pressure, velocity and temperature values at the 1D-CFD interfaces





Multiscale – coupling procedure

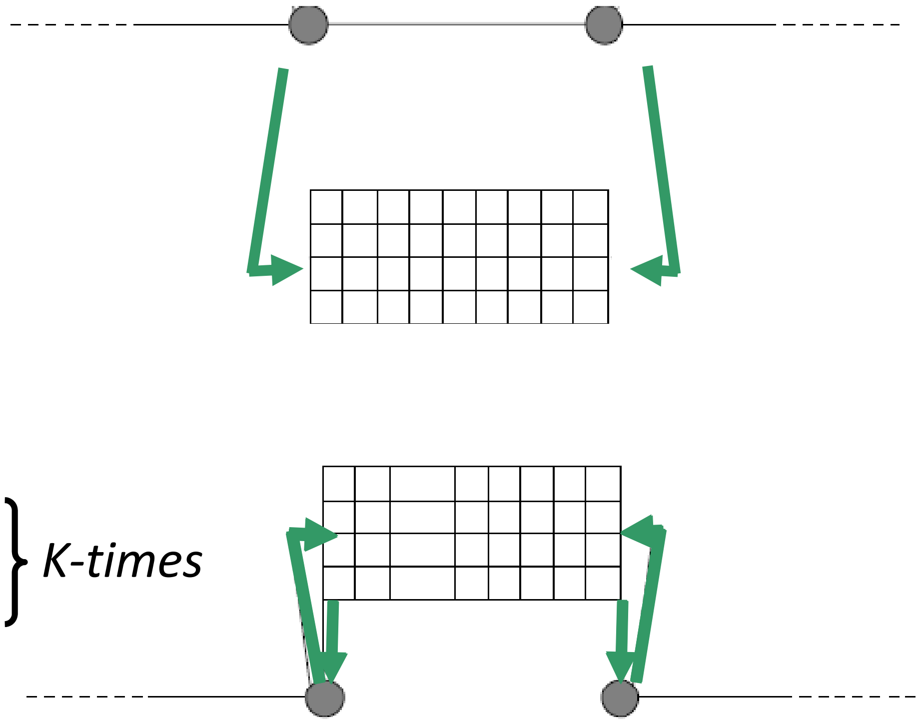
Coupling stages

1 - Full 1D model

2 - CFD model near field

3.a – 1D model far field
3.b - CFD model near field

K-times



Proceed to the next time step when some global convergence is reached

Multiscale - characteristics

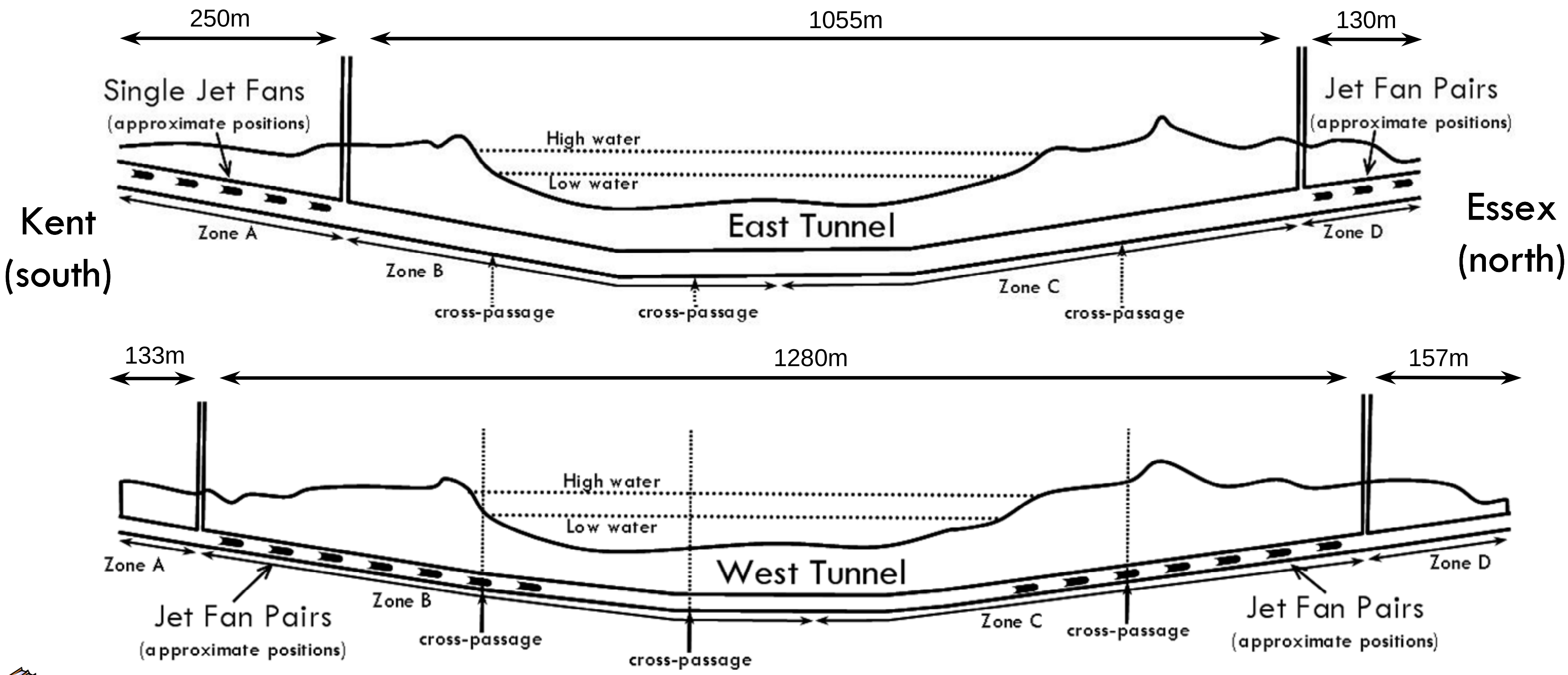
- Dramatic_reduction of the computational time (up to 2 orders of magnitude for a 1.2 km long tunnel)
- As accuracy as CFD
- Successfully used for parametric studies

BUT

- The placement of the 1D-3D interfaces is an issue
- Higher set up time than CFD
- The CFD solver has to be accessed by the user during the iteration algorithm (i.e. compiled UDF for FLUENT)

Simulation of tunnel ventilation flow

East & West Dartford tunnels (UK)



Colella, F., et al (2010), *Tunnel. Underg. Space Technol.*

Colella F et al (2009) *Building and Environment*

Simulation of tunnel ventilation flow

East & West Dartford tunnels (UK)

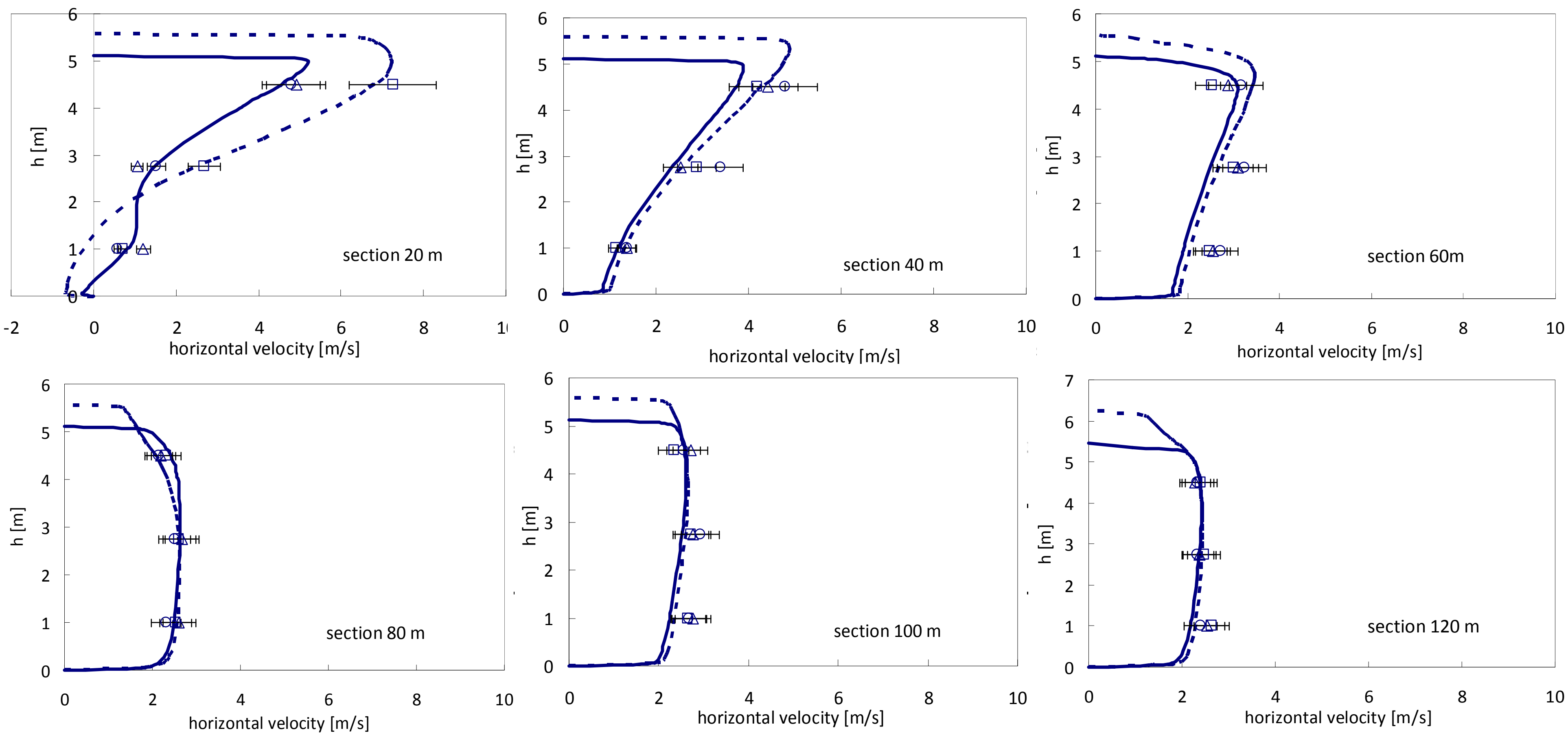
- ≈1500 m long with hybrid ventilation system
- **East tunnel** diam 9.5 m (1980)
- **West tunnel** diam 8.6 m (1963)
- 2 supply & extraction ventilation stations in the vicinity of the portals
- 28 jet fans in the **West Tunnel**
- 11 reversible jet fans in the **East tunnel**

Colella, F., et al (2010), *Tunnel. Underg. Space Technol.*

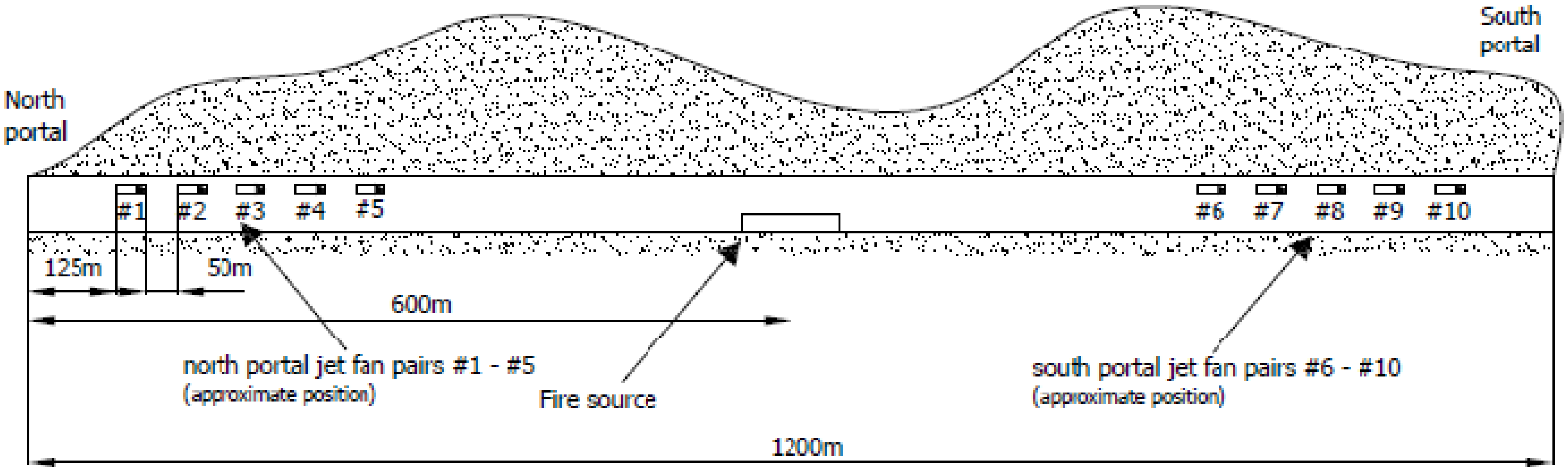
Colella F et al (2009), *Building and Environment*

Simulation of tunnel ventilation flow

West Tunnel Jet fan near field

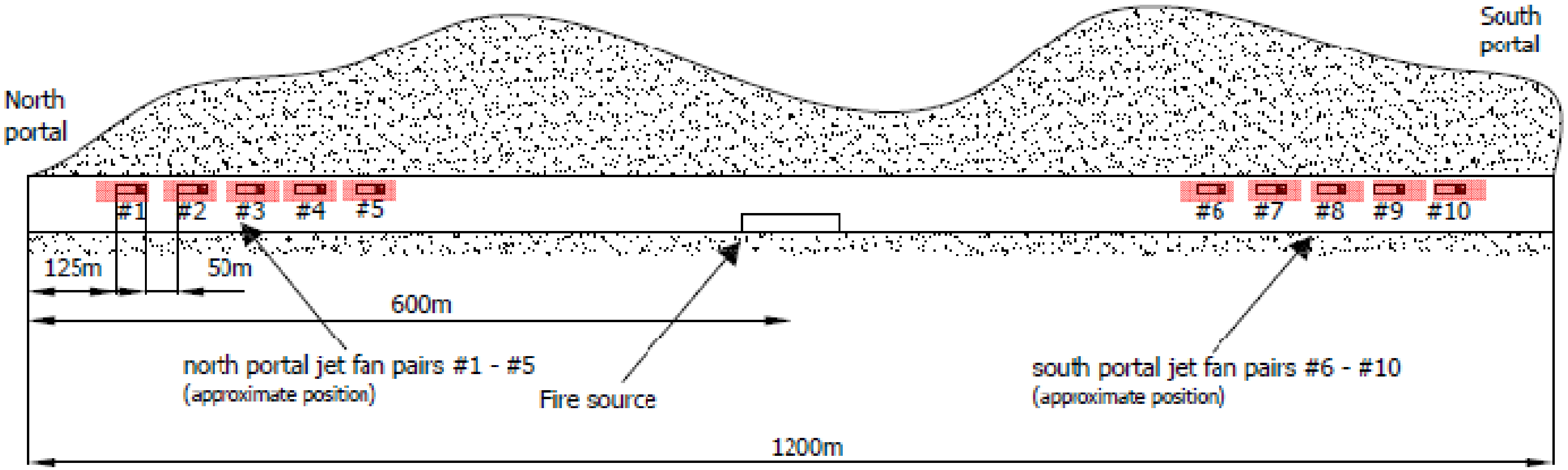


Simulation of tunnel fire scenarios



- 1200 m long longitudinally ventilated
- 10 pairs of jet fans (50m spaced, 34 m/s discharge air velocity)
- Fire located in the centre of the tunnel
- Fire max HRR: from 10 MW to 100 MW

Simulation of tunnel fire scenarios

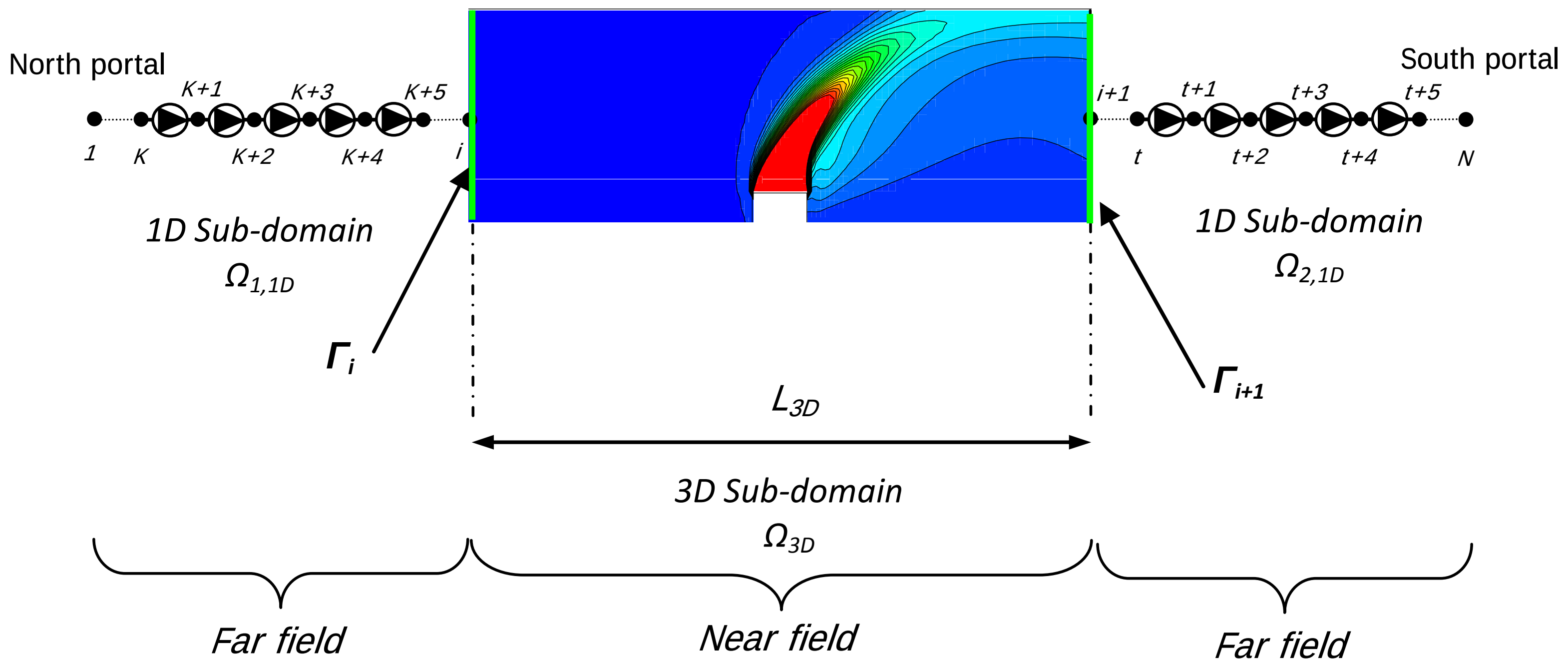


- Ventilation scenarios
  - Scenario 1: 3 jet fan pairs
  - Scenario 2: 5 jet fan pairs
  - Scenario 3: 10 jet fan pairs

Simulation of tunnel fire scenarios

Fire near field

Multiscale arrangement



Dipartimento di Energetica – Politecnico di Torino

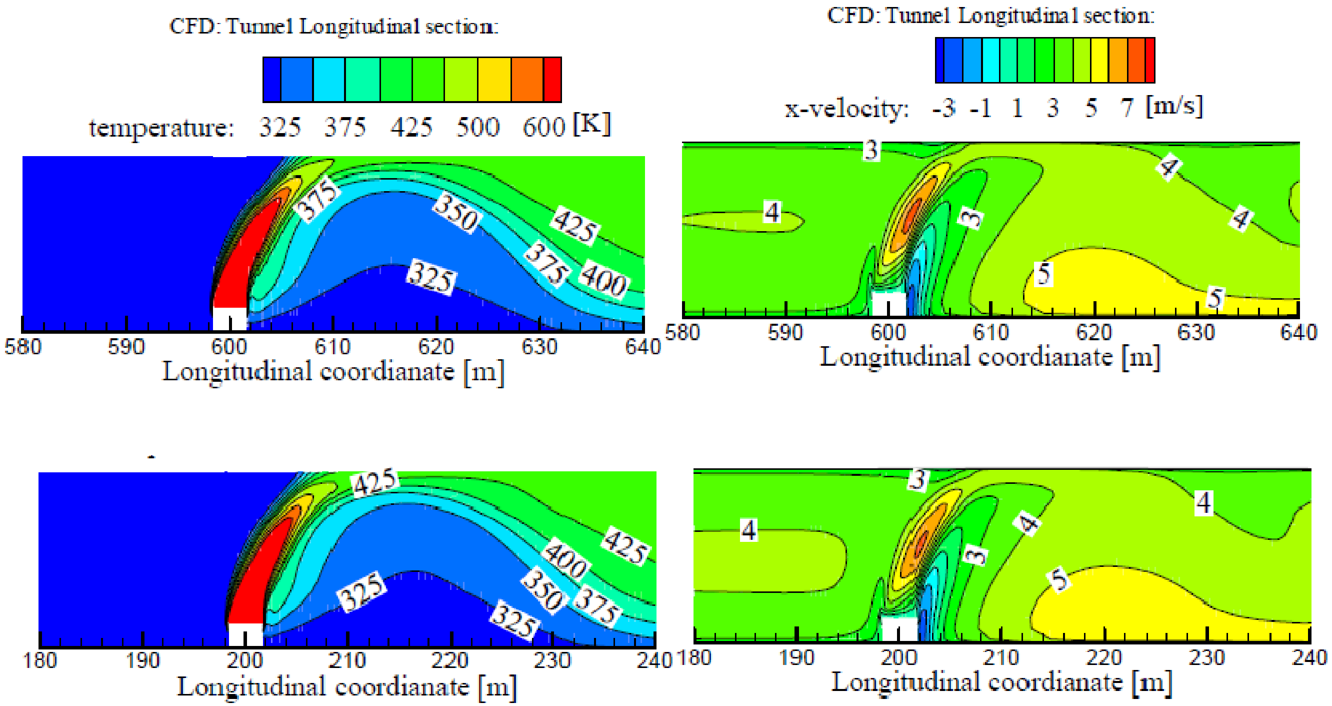
Steady state results

Comparison to full CFD solutions (30 MW fire)

Scenario 1: 3 Jet fan pairs

full CFD

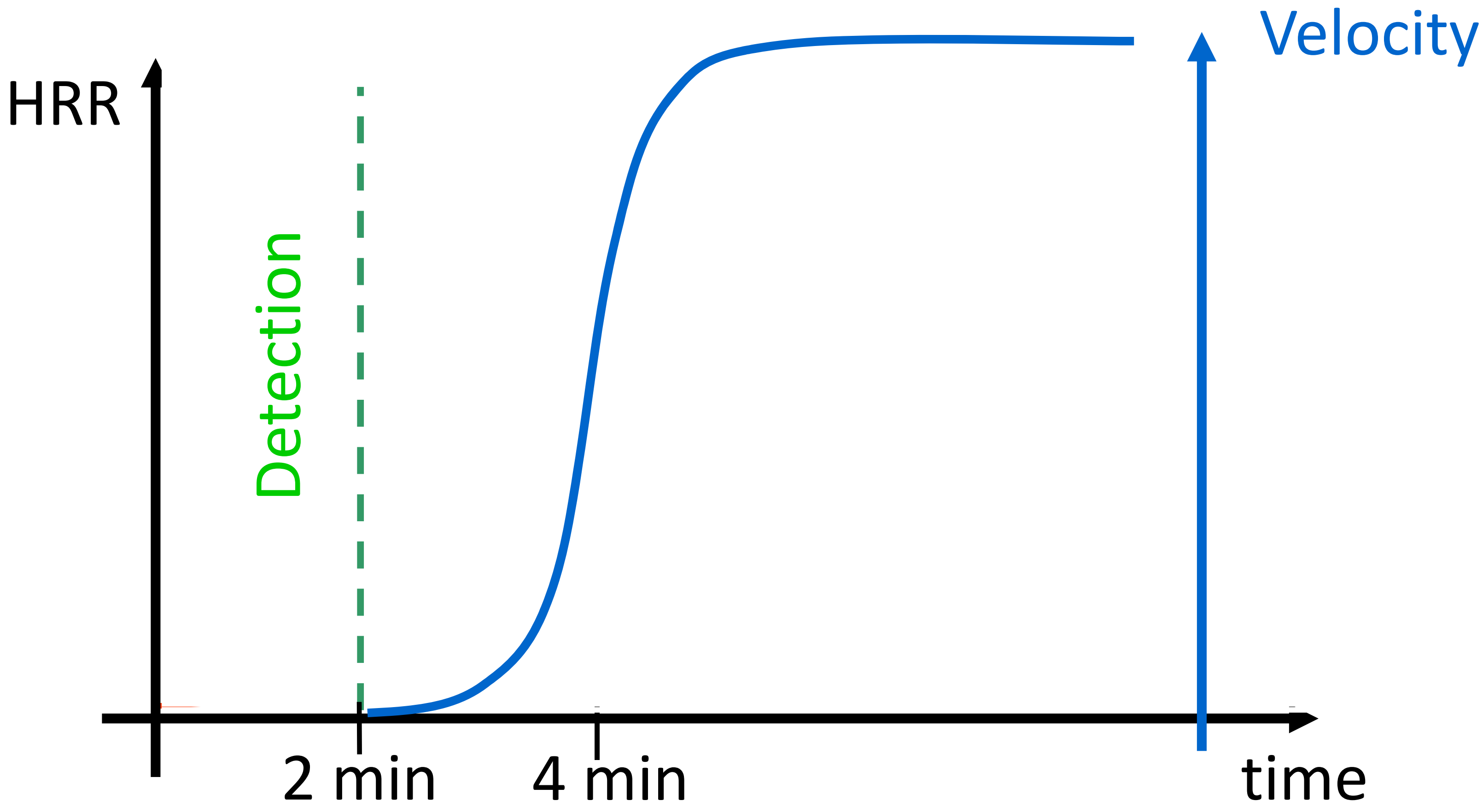
Multiscale



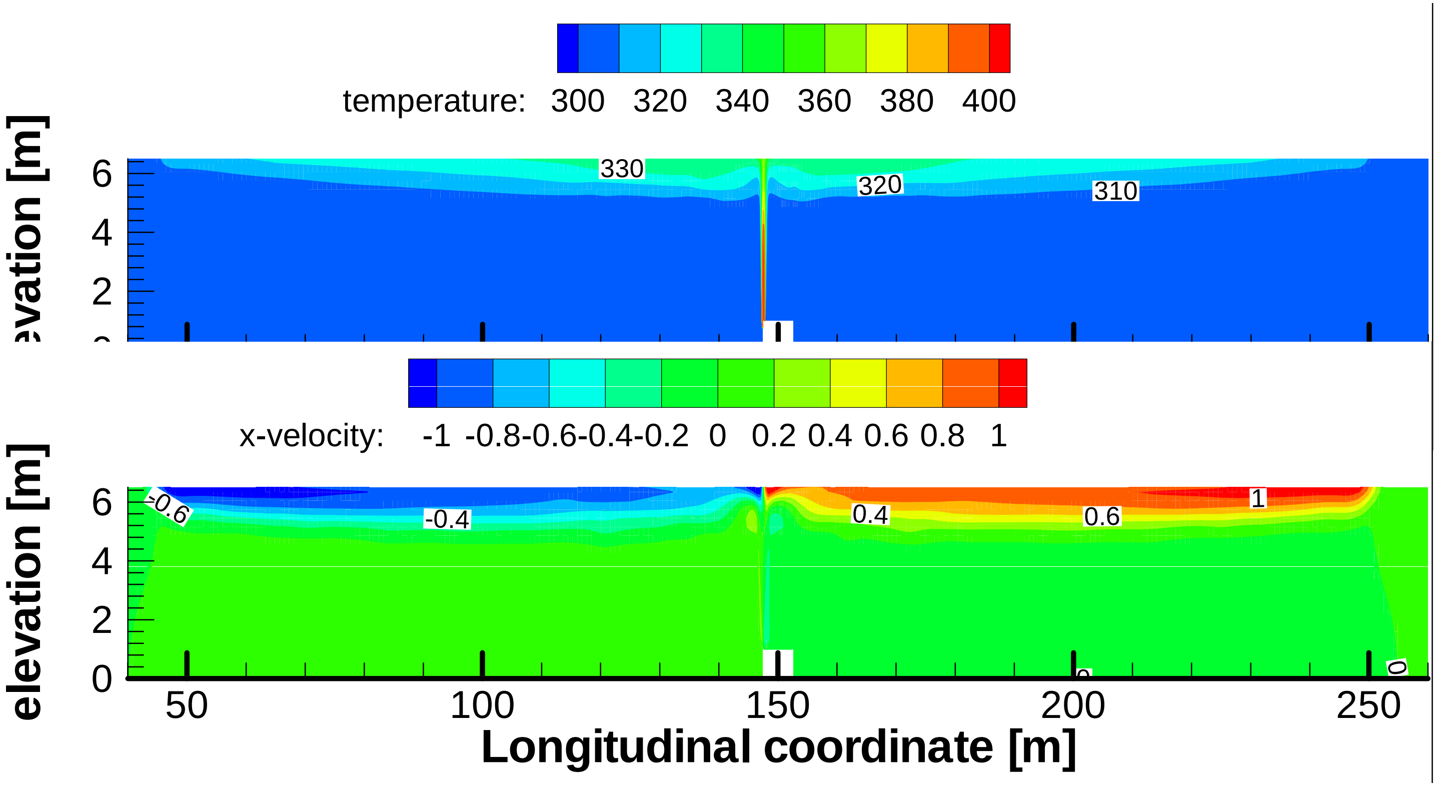
Highly accurate results are achieved!

Colella F., et al., *Fire Technology*, (in press).

Time dependent results

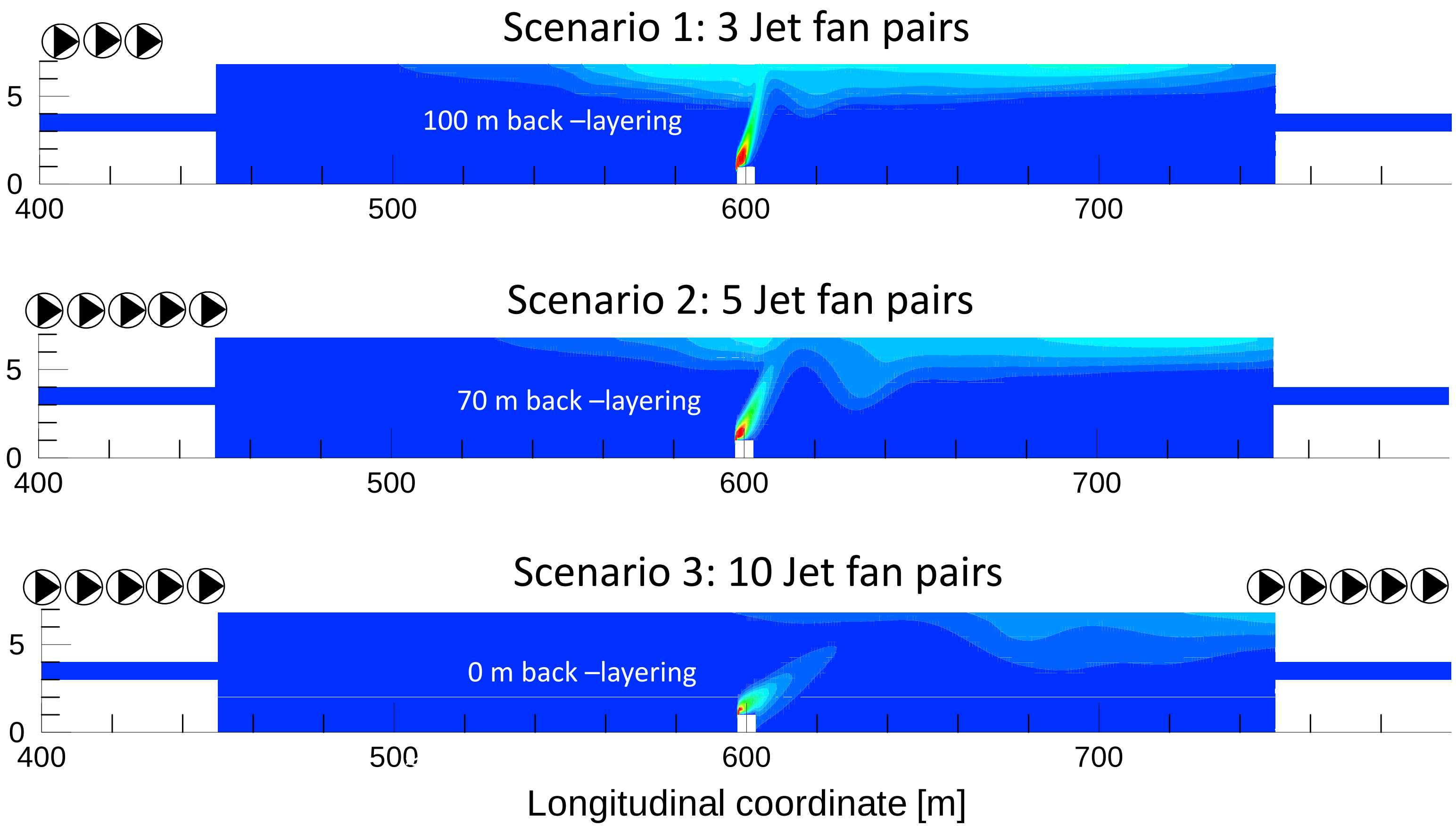


Multiscale results: 2 minutes



Time dependent results

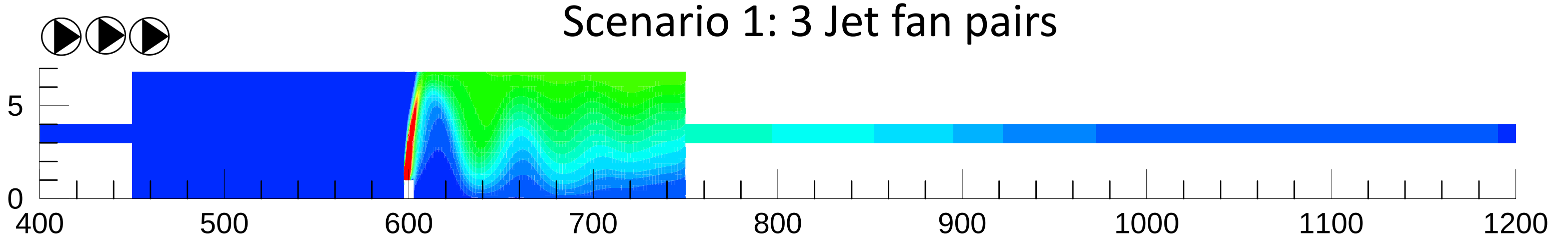
Multiscale results: 3 minutes



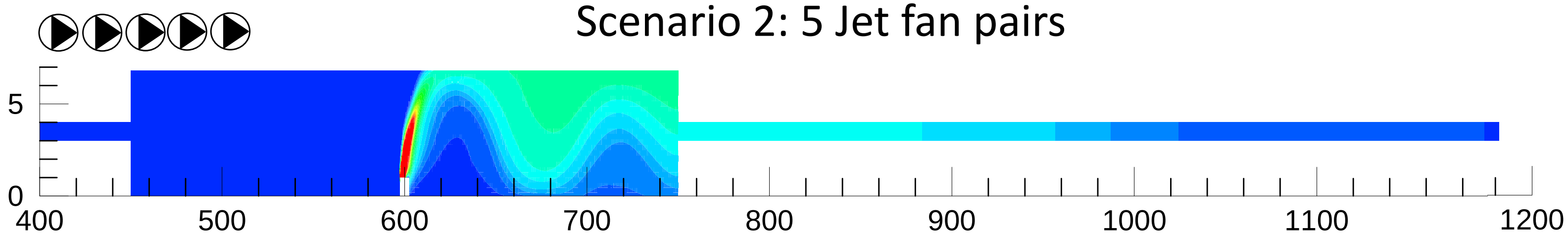
Time dependent results

Multiscale results: 5 minutes

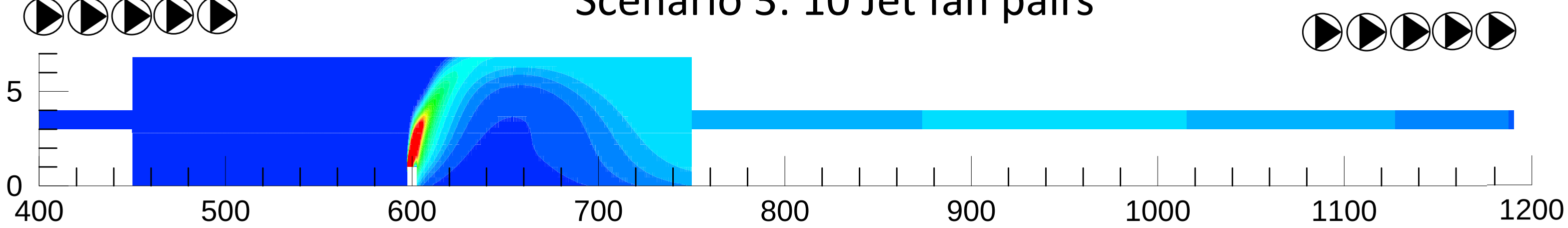
Scenario 1: 3 Jet fan pairs



Scenario 2: 5 Jet fan pairs



Scenario 3: 10 Jet fan pairs



Conclusions (1)

Several numerical techniques have been used to deal with ventilation and fire induced flows in tunnels

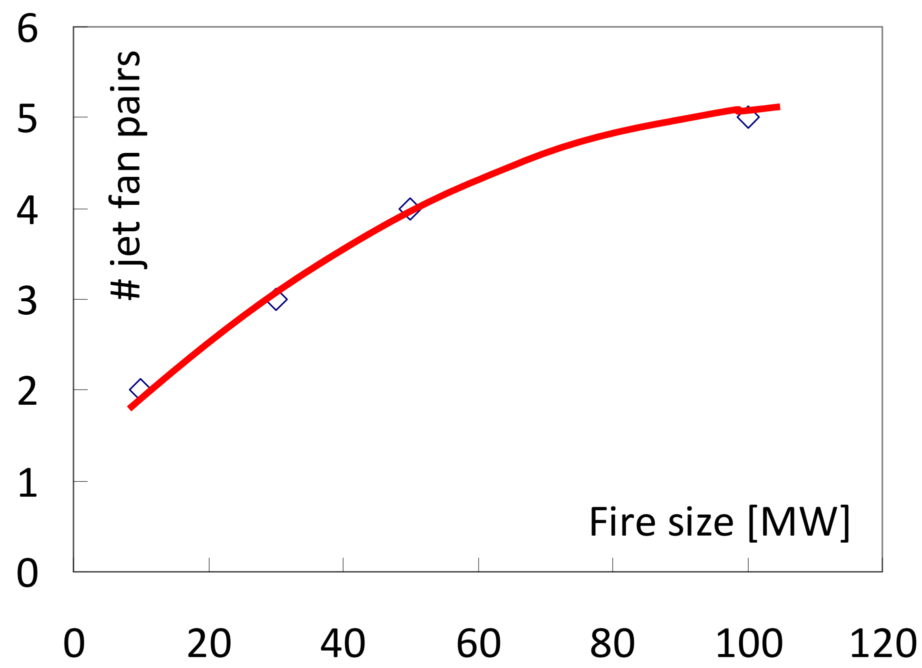
- 1D and CFD models
- Multiscale models
  - Dramatic reduction of the computational time (up to 2 orders of magnitude)
  - As accurate as full CFD
  - Results agree well with experimental measurements
  - **Allow for full coupling of fire and ventilation system and complete analysis of ventilation system response**
  - Well suited to conduct parametrical studies, sensitivity analysis, redundancy studies and Detection/Activation/propagation problems

Conclusions (2)

Evaluation of Fire throttling effect

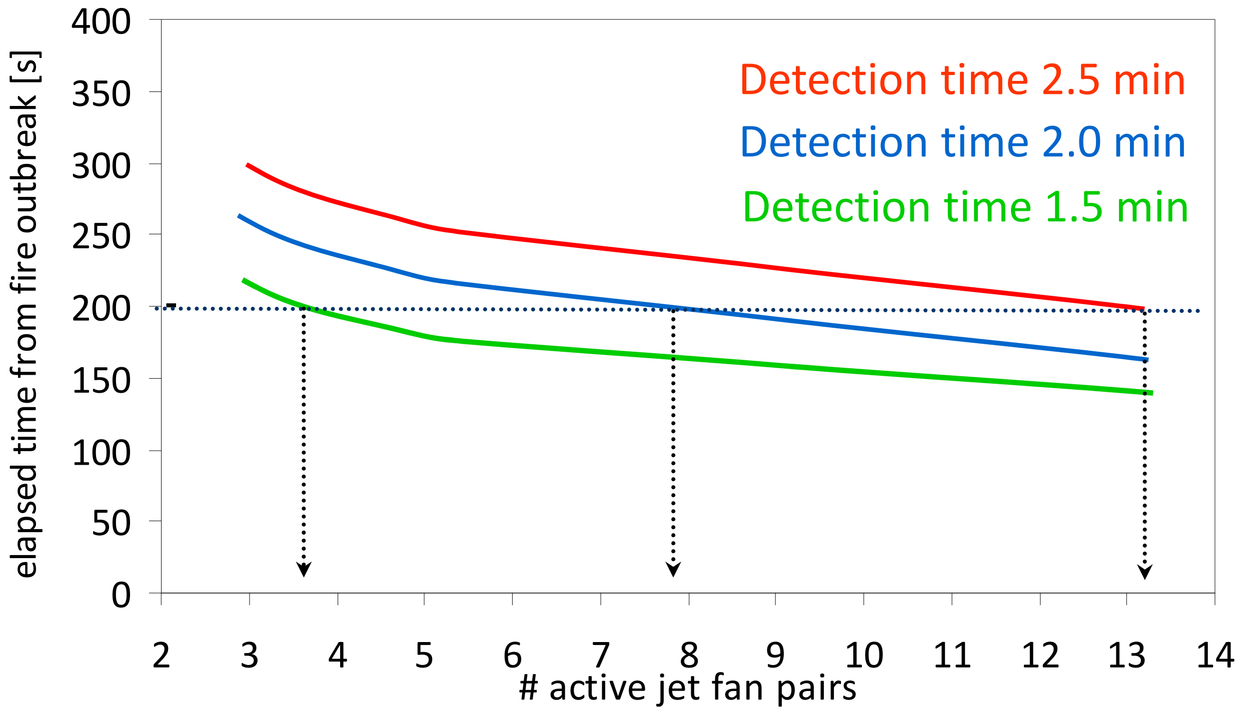
(…. the additional fire induced pressure losses due to sudden air expansion, higher velocities, buoyant effects and localized losses in the plume region. …. amplified for larger fires and longer tunnels…)

- Require a global simulation of tunnel and ventilation system to be evaluated
- **Can be significant for large fires (>100 MW) and long tunnels!**
- The number of jet fan pairs required to achieve critical velocity is highly dependent of the fire size



Conclusions (3)

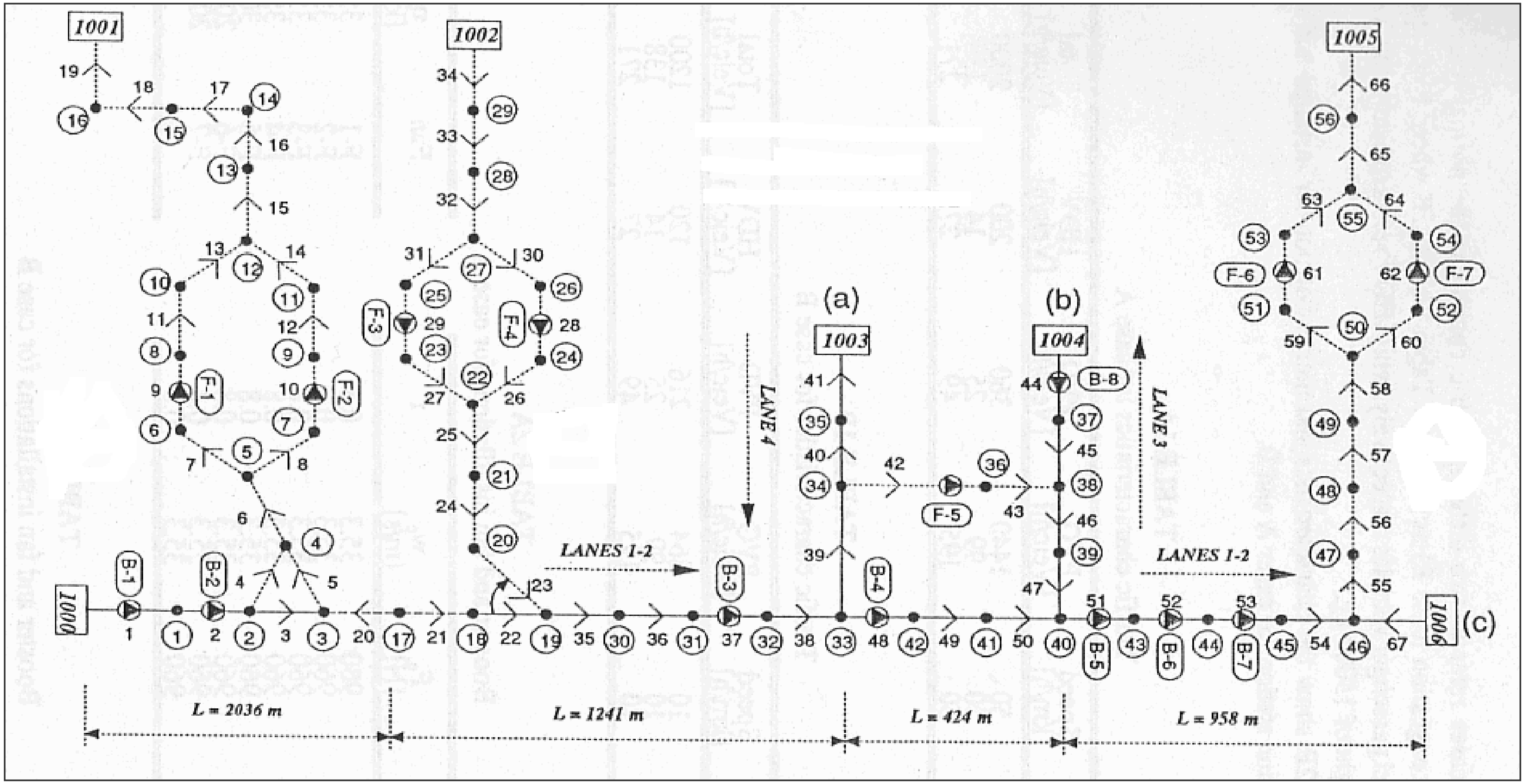
Evaluation of the ventilation system response (Time required to remove back-layering)



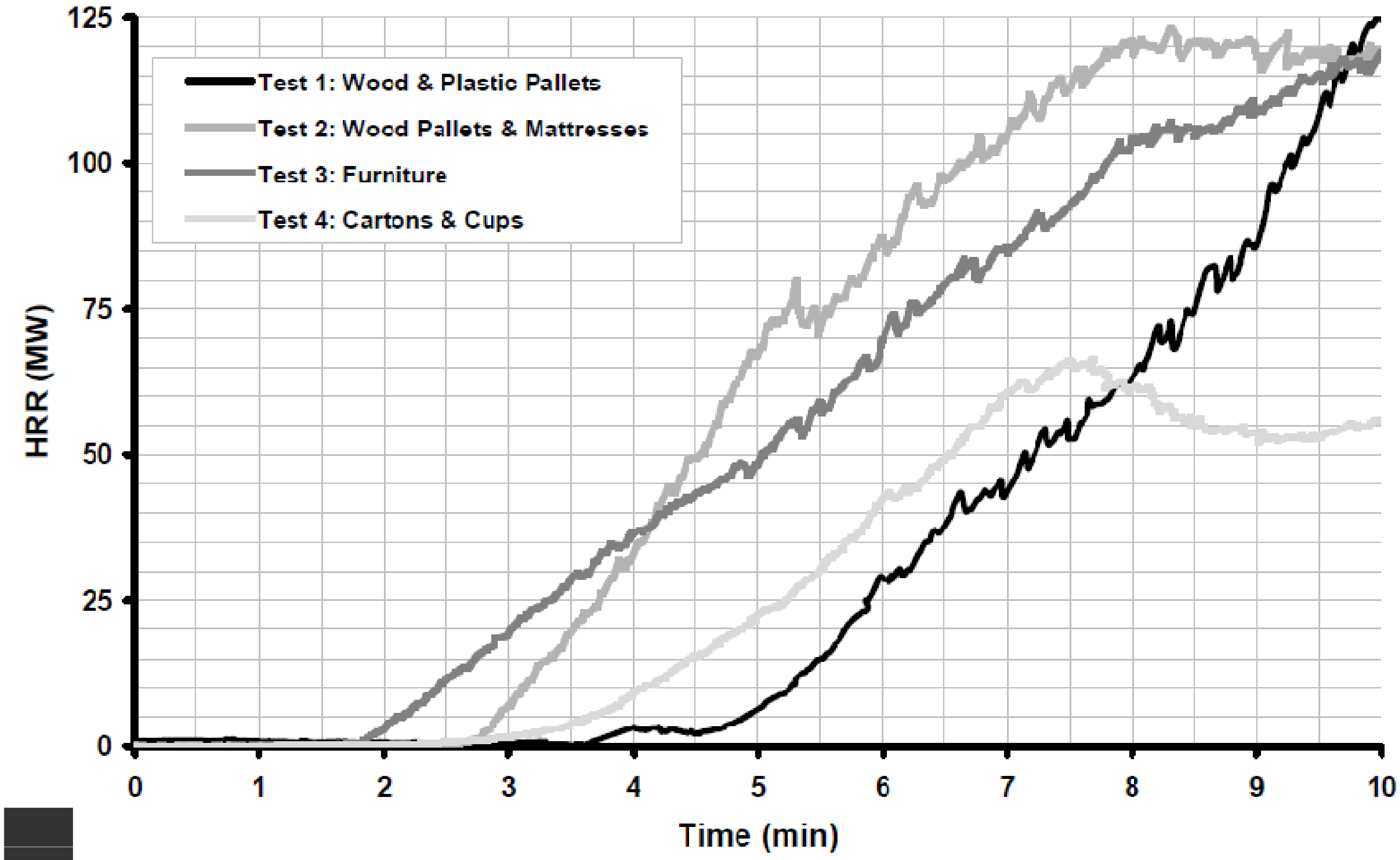
Significant impact of detection time on ventilation system response!

Any questions?

Tunnel ventilation models - Network

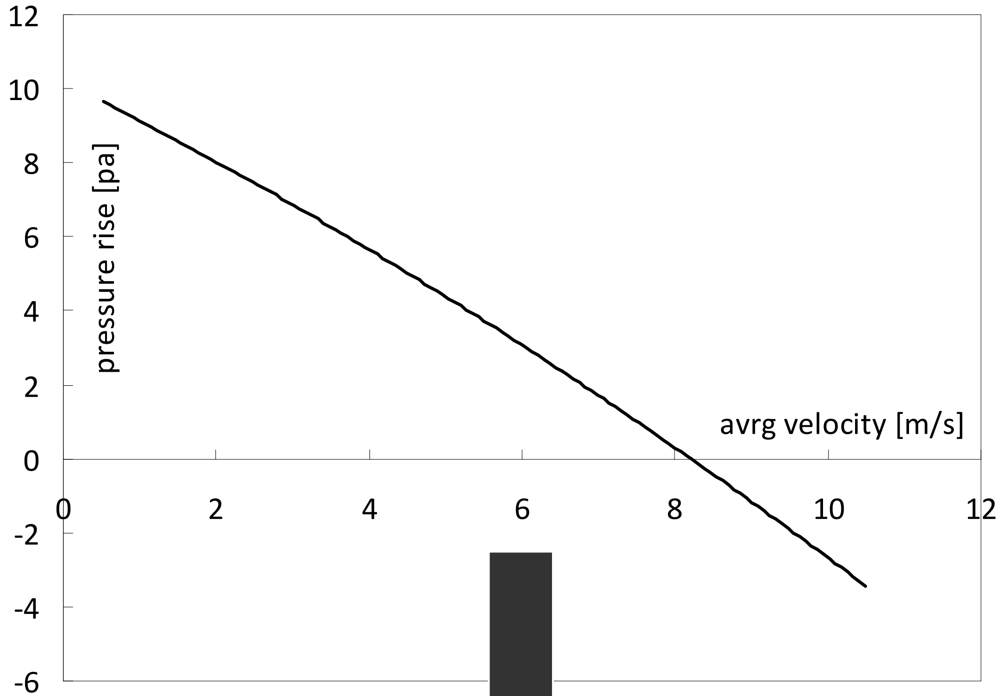


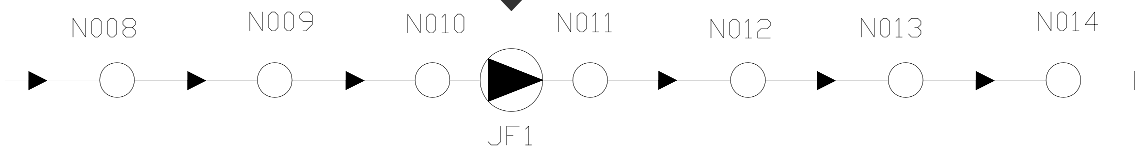
Modelling techniques – 1D Network



Modelling techniques – 1D Network

Jet fan characteristic curve





Multiscale – coupling procedure